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# Prey and Plastic Ingestion of Pacific Northern Fulmars (*Fulmarus glacialis*) Collected in Monterey Bay, California

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PREY AND PLASTIC INGESTION OF PACIFIC NORTHERN FULMARS  
(*FULMARUS GLACIALIS*) COLLECTED IN MONTEREY BAY, CALIFORNIA

A Thesis

Presented to

The Faculty of Moss Landing Marine Laboratories

and the Department of Biology

California State University, San Jose

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

Erica L. Donnelly

May 2012

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by

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DEPARTMENT OF BIOLOGY

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May 2012

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## ABSTRACT

### PREY AND PLASTIC INGESTION OF PACIFIC NORTHERN FULMARS (*FULMARUS GLACIALIS*) COLLECTED IN MONTEREY BAY, CALIFORNIA

By Erica L. Donnelly

Marine plastic pollution affects seabirds that mistake it for prey or incidentally ingest it with prey. Northern Fulmars (*Fulmarus glacialis*) and seabirds that feed at the water's surface ingest the most plastic. This can cause health issues, including satiety that possibly leads to inefficient foraging. The objectives of this study were to examine fulmar body condition, identify cephalopod diet and ingested plastic, predict foraging areas, and determine if prey number and size was correlated with ingested plastics in Pacific Northern Fulmars (*Fulmarus glacialis rogersii*). Cephalopod prey were identified, measured, and enumerated; plastic and marine debris were categorized, enumerated, and weighed from beach-cast Northern Fulmars wintering in Monterey Bay, California, during 2003 and 2007. Fulmars ate mostly Gonatid squids (*Gonatus pyros*, *G. onyx*, and *G. californiensis*) in similar size classes for both years. There was a significant negative correlation between pectoral muscle index and average size of cephalopod beaks per stomach, a significant increase in multiple plastic categories between years, and no significant correlation between the number and mass of plastic compared with the number and size of prey for either year. Although there was no correlation between plastic and prey, other issues with ingested plastics (contaminant accumulation, endocrine disruption, and micro plastics) should be further examined as plastic pollution increases in the world's oceans.

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## **Introduction**

Plastic waste occurs throughout the world's oceans as surface, bottom, or coastline debris, and often becomes aggregated in convergence zones (Shaw & Mapes 1979). Winds, currents, and geographic inputs aggregate plastic at convergence zones (Shaw & Mapes 1979, Dameron 2007, Pichel et al. 2007), which are important foraging areas for pelagic seabirds, marine mammals, and turtles, thus increasing their chances of ingesting plastic (Polovina et al. 2001, Seki et al. 2002, Pichel et al. 2007).

Seabirds that feed at the water's surface (e.g. Procellariiformes; Albatrosses, Petrels, and Fulmars) ingest the most plastic (Nevins et al. 2005). Procellariiforms that forage at the water's surface are opportunistic, and presumably mistake floating plastic for prey items. Bottle caps, cigarette lighters, balloons, toys, and other fragments have been recovered from Procellariiforms with increasing frequency (van Franeker & Meijboom 2002, Nevins et al. 2005, Mallory et al. 2006). Furthermore, prey can be attached to floating debris and ingested by seabirds (i.e., flying fish deposit their egg masses on floating debris; Sileo et al. 1989).

Documented cases of plastic ingestion by Northern Fulmars are rapidly increasing in regions of the North Atlantic (Moser & Lee 1992, van Franeker & Meijboom 2002) and North Pacific (Robards et al. 1995, Nevins et al. 2005, Mallory et al. 2006). Greater than 80% of fulmars sampled from the Atlantic and Pacific from 1975 to 1990 contained plastics (van Franeker 1985, Moser & Lee 1992, Robards et al. 1995). Recently, 71-88% of Pacific fulmars (Robards et al. 1997, Nevins et al. 2005) and 95-99% of North Atlantic

fulmars (*Fulmarus glacialis glacialis*) contained some form of plastics (van Franeker & Meijboom 2002).

Programs monitoring marine litter have indicated increased ingestion of plastics in Northern Fulmars (van Franeker et al. 2005). The programs keep detailed accounts of plastic debris in Northern Fulmars, and enable regular monitoring of abundance of litter in foraging areas (van Franeker & Meijboom 2002). In addition to plastic, stomachs also contain indigestible hard parts of prey items (e.g. squid beaks, fish otoliths, and invertebrate exoskeletons) used to determine prey size and species. Fulmars in the Pacific eat primarily cephalopods and fish (Baltz & Morejohn 1977, Harrington-Tweit 1979, Hunt et al. 1981, Sanger 1983, Hills & Fiscus 1988, Gould et al. 1997), whereas fulmars in the Arctic and Atlantic consume more fishes (Cherl et al. 2001). Van Franeker and Meijboom (2002) examined the stomach contents of 329 fulmars washed ashore between 1982 and 2000 in the North Atlantic. They reported 78% of fulmars had prey remains (all types totaled), and 96% contained plastic. These findings indicate that incidence of plastic in Northern Fulmars is greater than prey, and may result in health complications in fulmars.

Direct and indirect health effects are associated with plastic ingestion. Effects include reduced hunger (satiety), internal blockage, contaminant accumulation, and negative correlations between bird fat indices or mass in relation to ingested plastic (Pettit et al. 1981, Day et al. 1985, Zonfrillo 1985, Frey et al. 1987, Pierce et al. 2004, Mallory et al. 2006). Inability or difficulty regurgitating hard material (plastics and prey

parts) can interfere directly with the bird's digestion causing gastrointestinal blockage (Day 1980, Pierce et al. 2004) or indirectly by reducing feeding stimulus and activity (Sturkie 1965 as cited in Azzarello & Van Vleet 1987). Unlike most seabird species, Northern Fulmars have a constriction between the gizzard and proventriculus making regurgitation improbable (Furness 1985, Azzarello & Van Vleet 1987). As a result, plastics and prey hard parts (e.g., cephalopod beaks) are retained for an unknown amount of time.

In addition to the constriction, the gizzard is relatively small and susceptible to distension in individuals carrying large plastic loads. Distension of the gizzard in fulmars may lead to decreased stomach contractions (Day 1980). Contractions signal the absence of food, therefore, hunger and foraging effort would decrease as plastic loads increase (Connors & Smith 1982, Day et al. 1985, Ryan 1988). In addition to satiation effects, accumulated plastics may reduce maximum food load (volume of food that can be ingested in one foraging bout; van Franeker & Meijboom 2002). Presently, evidence for satiation effects are difficult to attribute solely to plastic ingestion, however, decreased sense of hunger, decreased urge to forage, and a decrease in ingested volume of food will negatively affect the condition of the bird, eventually resulting in mortality (Pierce et al. 2004).

Plastic often is not the direct cause of mortality, but it may reduce the physical fitness of the seabird. Decreased physical fitness can affect reproduction and decrease chances of survival (van Franeker & Meijboom 2002). In the 1980s, researchers reported

weak negative correlations between seabird body condition and mass, number, and volume of plastics (Day 1980, Furness 1985, Ryan 1987). Others indicated, however, significant, positive correlations when age and season were assessed as covariates (Connors & Smith 1982). Positive correlations were possible if plastic was concentrated in the same locations as prey and better foragers found the optimal foraging areas (Spear et al. 1995). Positive correlations also could be attributed to location of feeding (Young et al. 2009). Spear et al. (1995) was the first to report significant negative correlations between the number of plastic particles and body mass. These results and earlier negative correlations could result from one or a combination of the following: (1) direct damage or blockage of the digestive track or impairment of digestive efficiency; (2) indirect damage that caused reduced mass from toxins that leach from ingested plastic; and (3) the birds were already in poor body condition and ate more plastic due to reduced foraging efficiency (Spear et al. 1995). Although the third explanation is a possibility, it is inconsistent with the previous finding that birds in better body condition contained more internal plastic (Spear et al. 1995). Additionally, the prey may have ingested the plastic before the birds foraged on them (i.e. secondary ingestion; Eriksson & Burton 2003).

Of those previous researchers who reported negative correlations between bird mass and plastic load (Spear et al 1995, Sivert & Sileo 1993, Auman et al. 1997), none concurrently reported the prey remains in the seabirds. Previously, researchers have examined diet *or* plastic ingestion in Northern Fulmars, but have not examined both

variables together (Baltz & Morejohn 1977, Sanger 1983, Hills & Fiscus 1988, van Franeker & Meijboom 2002, Nevins et al. 2005). Frequency of occurrence and general types of prey ingested has been determined from Fulmar stomach contents, but prey identified to species, particularly cephalopods, has rarely occurred. Twelve cephalopod families were found in the stomach contents of Fulmars in the 1970s, 1980s, and early 1990s, but more recent identification of cephalopods from Northern Fulmar stomachs has not occurred. Furthermore, if greater plastic loads lead to satiety or reduced foraging efficiency in Northern Fulmars, a change in prey items (i.e. different size classes, species, frequency of occurrence, etc.) may occur. In this study, I examine the possible correlation between Northern Fulmar plastic loads and the occurrence and size of prey species because plastic loads may be influencing the types of prey ingested or vice versa.

Because fulmars foraging in the North Pacific contain increased plastics, birds may feel satiated and select prey that are easier to catch and will forage less often. Thus, I predicted smaller and fewer prey in Fulmars with greater amounts of plastic. Additionally, I identified prey to species taxa to test whether a shift to smaller prey also indicated a change from larger to smaller species eaten by fulmars had occurred. A natural shift of diet in Fulmars when prey availability is altered (Cherl et al. 2001; indicative of an opportunistic feeder) may complicate any shift in prey species selection with increasing plastic loads. Despite this shift, a change in the amount and size class of prey consumed should be observed when comparing birds with varying volumes of plastic debris. Because it is uncertain if fulmars of poor or healthy condition contain

greater plastic loads, I predicted that fulmars of poor condition would have significantly greater plastic loads. Fulmar condition will be based on subcutaneous fat and pectoral muscle indices. Interannual differences in oceanic conditions also are important in determining which prey are available to fulmars.

Pelagic seabirds, including Northern Fulmars, forage over large spatial scales. Studies of prey of pelagic seabirds, therefore, provide natural indices of food web composition, location of prey, and relative abundance of prey among years in relation to oceanographic conditions (Montevecchi & Myers 1996, Sydeman et al. 2001). Changes in prey selected by Northern Fulmars, therefore, may be in response to short-term fluctuations in prey abundance (Suryan et al. 2002). Discriminatory prey choice in some seabirds, however, also has been documented (i.e., some prey items were over or under-represented, relative to their abundance; Suter 1997, Suryan et al. 2002).

The abundance and availability of cephalopods, the primary prey of fulmars, are influenced by variable oceanic conditions, prey movements, behavior, and life-cycle characteristics that are species-specific (Boyle & Boletzky 1996, Rodhouse & Nigmatullin 1996). Cephalopod beaks recovered from seabirds and other marine predators can be used to determine prey species and contribute to indirect population assessments of cephalopods and determine aggregation areas (Clarke et al. 1986, Boyle & Boletzky 1996). If deeper-water cephalopods (e.g., Gonatidae) dominated Northern Fulmar diet, I predicted there would be no significant difference relative to oceanic conditions, because mesopelagic and deep-water squids should be less influenced by

dynamic oceanic conditions than surface-dwelling squid (e.g. *Dorytheuthis opalescens*). Overall, I predicted that Fulmars carrying greater internal plastic loads would contain the least amount of cephalopods and the smallest size class of cephalopods regardless of oceanic conditions.

## **Methods**

Northern Fulmars that washed ashore in the Monterey Bay area in 2003 and 2007 were collected by volunteer beach-walkers and later necropsied at the Marine Wildlife Veterinary Care and Research Center [California Department of Fish and Game, Santa Cruz, California (CDFG)]. One hundred eighty five dead fulmars were collected in 2003, and 111 dead (named SCD) and 74 live (named SCL) were collected in 2007. Those collected live died within one week and were then sampled. Carcasses were necropsied within 24 h of collection or frozen at -20°C until 12 to 24 h before necropsy when they were thawed at room temperature. Morphometrics were determined for each bird (head length, bill depth at gonys, bill length, tarsus length, flattened wing chord were measured to the  $\pm 1$  mm). Body condition indices were based on condition of the pectoral muscle and quantity of subcutaneous fat (van Franeker & Meijboom 2002). Both indices were scored 0-3, where 0 indicates total depletion and 3 is optimal condition. Additionally, pectoralis, liver, and stomach tissues were sampled (van Franeker & Meijboom 2002 for detailed protocol). Stomachs were dissected out by severing the esophagus at throat-level and at the intestine under the ventriculus. The stomachs were refrozen and processed at a later time. The sex and body condition of the birds were noted based on internal organ



inspection. Body condition was an assessment of internal/external injuries while noting the presence or absence of fractures, internal bleeding, and bruising. For this study, sex and age class were referred to as demographics, while pectoral muscle index and subcutaneous fat indices were referred to as body condition.

Age estimates were based on the development of the sex organs (size, shape, and color) and the presence and size of the Bursa Fabricius. For males, testis length and width were measured ( $\pm 1$  mm), and color was noted (dark, bi-colored, pink, or whitish). In females, ovary length and width and the diameter of the largest follicle were measured ( $\pm 1$  mm). An oviduct development score (1 to 4 from juvenile to breeding adult) was assigned (Van Franeker & Meijboom 2002). Age estimates were assigned as juvenile (1<sup>st</sup> year), immature (incomplete development of sex organs; estimated 2-6 years old), and adult (organs show signs of previous breeding or full capability to breed; van Franeker & Meijboom 2002). The presence and size of the Bursa of Fabricius was noted; it was assumed that only juvenile and immature birds ( $\leq 1$  year) contained prominent bursas (van Franeker & Meijboom 2002).

Stomachs were processed after necropsy of the fulmars. The proventriculus and ventriculus later were thawed and processed separately for the 2007 samples. The proventriculus was severed from the ventriculus and both were weighed before dissection, opened full length, flushed with water to collect contents, and weighed after dissection (van Franeker & Meijboom 2002). Flushed particles were collected in a 0.5 mm mesh sieve and rinsed to remove prey soft tissues. Hard parts, plastics, and other

remaining non-food hard particles were collected from the sieve and placed in a segregated Petri dish; (the 2003 samples were previously processed by MLML students) and the stomach contents were saved in glass vials where plastics, parasites, and cephalopod beaks were stored separately. I separated the plastics into segregated Petri dishes, following the protocol of van Franeker & Meijboom (2002), for further processing and analyses. A binocular microscope was used to separate items into specified categories (prey, natural items, user plastics, industrial plastics, etc.). Cephalopod beaks were placed separately in small Nalgene or glass vials and saturated in 70% isopropyl alcohol to prevent drying.

Once separated, the plastics were quantified by frequency of occurrence, number of particles, total mass, and relative mass compared with proportion of other matter in stomach. Plastics were dried, weighed, counted, and categorized for each sample (van Franeker & Meijboom 2002). The primary plastic categories for my study were industrial plastics (pre-molded pellets used in manufacturing), user plastics (all non-industrial remains of plastic objects such as sheet-like plastics, threads, rubbers, and foam), all plastic (both industrial and user), and all debris (includes all plastics and other non-plastic man-made debris and chemicals).

Fish otoliths were eliminated from the analyses due to extensive degradation (> 10 total, they crumbled when touched with forceps). Cephalopod beaks were examined using a dissecting scope, measured with digital calipers, and identified to lowest taxonomic level using physical descriptions, reference collections, and literature sources

(Clarke et al. 1986, William Walker unpublished beak guide illustrations 2009, National Marine Fisheries Service, National Marine Mammal Laboratory, Seattle reference collection). Lower cephalopod beaks were measured to the nearest 0.1 mm. Estimated dorsal mantle length (DML) and mass of the cephalopod prey were determined using the lower beak rostral length (LRL) measurements and published regression equations (Wolff 1984, Clarke et al. 1986, Walker in press). Based on species and beak size, the cephalopods were categorized as surface-dwelling, mesopelagic, or deep-sea squids.

To examine how oceanic conditions might influence foraging, oceanic conditions and fulmar tracking were examined using published sources. I used California Cooperative Oceanic Fishery Investigations (CalCOFI) reports to examine inshore and offshore changes of abiotic and biotic factors in the California Current System (CalCOFI Rep. Vol 45-50). Fulmars sampled from 2003 were grouped as “warm-water,” and those sampled from 2007 were grouped as “cold-water.” This was based on CalCOFI reports that El Niño-like conditions occurred during 2003 and La Niña conditions occurred during 2007 (CalCOFI Rep. Vol 45-49). Fulmar foraging areas were predicted using tracking data from previously tagged fulmars from Alaskan colonies in 2002 and 2003 (Hatch et al. 2010).

## **Statistics**

Initially, cephalopod prey items were analyzed separately from plastic items. I described feeding strategy and diet diversity using a modified version of the Costello Method and the Shannon-Wiener diversity index (Amundsen et al. 1996, Zar 1999). The

Amudsen modification to the Costello Method plots the prey-specific abundance, %PN, against the frequency of occurrence, FO (expressed in fraction rather than in percent).

The modification “allows prey importance, feeding strategy and the inter- and intra-individual components of niche width” to be examined (Amudsen et al. 1996, Fig. 1).

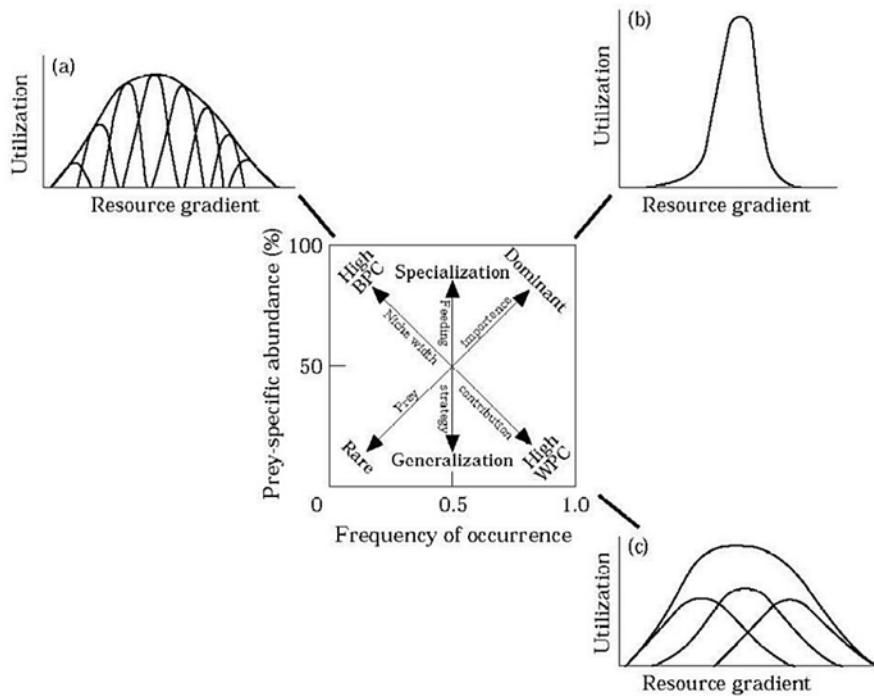
Prey-specific abundance was defined as:

$$P_i = (\sum S_i / \sum S_t) * 100$$

where  $P_i$  is the prey-specific abundance of prey  $i$ ,  $S_i$  is number of prey  $i$ , and  $S_t$ , the total number of items in the stomach only for those predators with prey  $i$  in their stomach (Amudsen et al. 1996). The Shannon-Wiener diversity ( $H'$ ) index measures diversity in categorical data using the number and evenness of the species. Greater species evenness or the addition of more species increases the index that is defined as

$$H' = -\sum_{i=1}^s (p_i \ln p_i)$$

where  $p_i$  is the relative abundance of each species calculated as the number of species ( $n_i$ ) divided by the total number of individuals ( $N$ ) evaluated for all species ( $s$ ).



*Figure 1.* Graphical analysis of feeding strategy diagram reprinted from Costello et al. 1996 indicating interpretation of feeding strategy, niche width contribution, and prey importance, and characteristic niche curves. (a) High between-phenotype component to niche width, (b) narrow niche width, and (c) high with-in phenotype component.

Estimates of dorsal mantle length (DML) and mass of cephalopods were plotted in frequency histograms. Multivariate Analysis of Variance (MANOVA with 9999 permutations) tested for differences in prey and plastics between the two years, the sexes, the ages classes (juveniles versus adults), and body conditions (healthy versus poor)

using R Enterprise Statistical Software. Because the majority of Fulmars were of poor condition in 2003 and there was not equal representation of healthy birds, both indices representing bird condition were removed from the analysis for with-in year comparisons.

Basic statistics were performed on the total number and mass of four plastic categories (total marine debris, all plastic, industrial plastic, and user plastics). The plastic data were ln transformed, and Analysis of Variance (ANOVA) tested for differences in the plastic categories between years. A Bonferroni correction was used to address the issue of multiple comparisons. Multivariate Analysis of Variance (MANOVA with 9999 permutations) tested for differences in plastic categories between the two years, sexes, age classes, and body conditions using R Software.

Finally, the prey items and plastic items were analyzed together. Canonical correlation analysis tested for correlations between the number and masses of the plastic compared with the number and size of prey species for each of the two years fulmars were collected (personal comm. Bros 2009). Only the user and industrial plastic categories were used in this analysis to eliminate some of the multicollinearity associated with total marine debris and total plastic categories.

## **Results**

Demographics and body condition indices revealed the sex, age group, subcutaneous fat index, and pectoral muscle index between both years; 2003 with mostly 0-1 indices and 2007 with a range of 0-3 indices (Table 1). The sex ratio was 50:50 in 2003 (for those in which sex could be identified; Nevins & Harvey 2005), but there were almost a third as many males as females in 2007 (Table 1). Both years were dominated by immature birds with lesser subcutaneous fat and lesser pectoral muscle indices indicating most birds were young and of poor health (Table 1).

Table 1

*Number of demographic measurements and body condition indices recorded for the Northern Fulmar samples collected in 2003 and 2007*

<b>Demographics</b>	<b>2003</b>	<b>2007</b>
<b>Sex</b>		
Female	68	63
Male	67	113
Unknown	43	9
<b>Age Group</b>		
Immature	145	164
Adult	0	18
Unknown	33	3
<b>Body Condition Indices</b>		
<b>SubQ Fat Index</b>		
0	141	125
1	0	38
2*	0	12
3*	0	3
Unknown	37	7
<b>Pec Muscle Index</b>		
0	0	51
1	140	95
2*	0	27
3*	0	4
Unknown	38	8

\* indicates 'healthy' code

*Note.* Subcutaneous fat is represented by “SubQ Fat Index” and pectoral muscle by “Pec Muscle Index.”

Diets were similar between years, but there were significant differences in the number of cephalopods eaten between years. The average number of beaks in 2007 ( $\bar{x}$  = 3.5, SE = 3.36, range = 0-15) was significantly greater ( $P$  = 0.03) than in 2003 ( $\bar{x}$  = 2.7, SE = 3.03, range = 0-13). I identified 1065 cephalopod beaks (542 for 2003; 523 for



2007) from fulmar stomachs. Fulmar diet was dominated by mesopelagic cephalopods of the family Gonatidae in both years (Table 2).

Table 2

*Occurrence (number of beaks) and zone distribution of identified cephalopods (family and species) from the stomachs of Northern Fulmar in 2003 and 2007*

Family	Genus/species	Beak Occurrence		Zone Distribution*
		2003	2007	
<b>Loliginidae</b>				epipelagic/continental shelf
	Doryteuthis opalescens	5	17	epipelagic/continental shelf
<b>Octopoteuthidae</b>		1		mesopelagic-bathypelagic/benthic-bathyal
	Octopoteuthis deletron	4	18	bathypelagic; epipelagic
	c.f. Octopoteuthis deletron		4	epipelagic/mesopelagic/benthic
<b>Gonatidae</b>		58	40	epipelagic/mesopelagic/benthic
	c.f. Gonatidae		3	mesopelagic; lower epipelagic; at the bottom in bathyal
	Gonatus pyros	132	149	mesopelagic; lower epipelagic; at the bottom in bathyal
	Gonatus berryi	26	23	mesopelagic; bathypelagic
	c.f. Gonatus berryi	2		mesopelagic; sometimes but rarely bathypelagic
	Gonatus californiensis	49	49	mesopelagic; sometimes but rarely bathypelagic
	Gonatus sp. c.f. G. californiensis	2		mesopelagic; lower epipelagic (at night)
	Gonatus onyx	144	83	mesopelagic; lower epipelagic (at night)
	c.f. Gonatus onyx	4		mesopelagic/bathypelagic/lower epipelagic
	Gonatus spp.	3	1	mesopelagic/bathypelagic/lower epipelagic
	Gonatopsis borealis	8	15	bathypelagic/meso-bathypelagic/sometimes bathyal
<b>Grimalditeuthidae</b>				
	Grimalditeuthis bonplandi		3	
<b>Histioteuthidae</b>				
	Histioteuthis heteropsis		2	
	Stigmatoteuthis dofleini	9	23	
	c.f. Stigmatoteuthis dofleini	1		
<b>Chiroteuthidae</b>				
	Chiroteuthis calyx	32	17	bathypelagic/meso-bathypelagic/sometimes bathyal
				epipelagic/mesopelagic/benthic
<b>Cranchiidae</b>		1		mesopelagic; bathypelagic
	Leachia dislocata		1	
	Cranchia scabra		1	
	Taonius borealis	28	21	mesopelagic; bathypelagic
	Taonius c.f. T. borealis		2	
	Taonius spp.	4	13	bathypelagic; bathyal (juv. epipelagic and mesopelagic)
	c.f. Taonius spp.	1		
<b>Mastigoteuthidae</b>				
	Mastigoteuthis pyrodes	4	4	
<b>Onychoteuthidae</b>				
	Onykia sp. c.f. O. robusta	1		
	Onykia spp.	1		
<b>Cirroteuthidae</b>				
	Cirroteuthidae c.f. Cirrothauma sp.	1		bathypelagic/benthic-bathyal/abyssal; ultra-abyssal
<b>Octopodidae c.f. Octopus rubescens</b>			1	n/a
<b>unidentified teuthid</b>		1		
<b>unidentified</b>	n/a	20	33	
<b>Totals</b>		542	523	* cited from Nesis 1987 Cephalopods of the World

The dominant species were *Gonatus onyx*, *Gonatus pyros*, and *Gonatus californiensis* (Table 2). Shannon-Wiener Diversity Index values of 2.46 for 2003 and 2.26 for 2007 are representative of an abundant and diverse prey community that is evenly distributed (Zar 1999). A subset of 931 beaks were suitable for measurement (474 for 2003; 457 for 2007). The average LRL was 3.76 mm (SE = 0.04) in 2003 and 3.80 mm (SE = 1.06) in 2007, which were not significantly different between years. Finally, histograms of the regressed dorsal mantle lengths and masses revealed similar size classes of cephalopods were eaten between the sampled years (Figs. 2, 3).

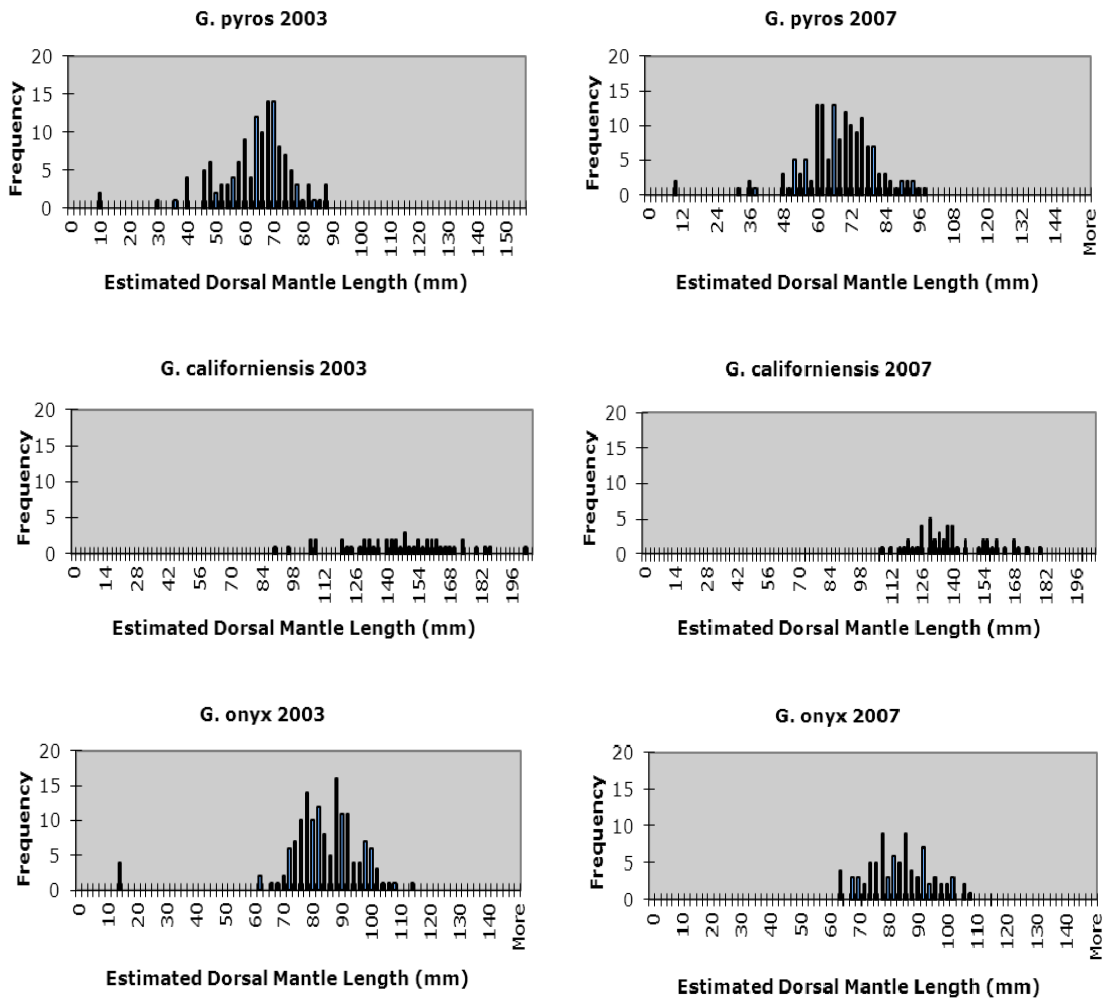


Figure 2. Distribution of estimated dorsal mantle lengths (mm) for *Gonatus pyros*, *G. californiensis*, and *G. onyx* in 2003 and 2007. Regressions were used from Wolff 1984, Clarke et al. 1986, and Walker in press.

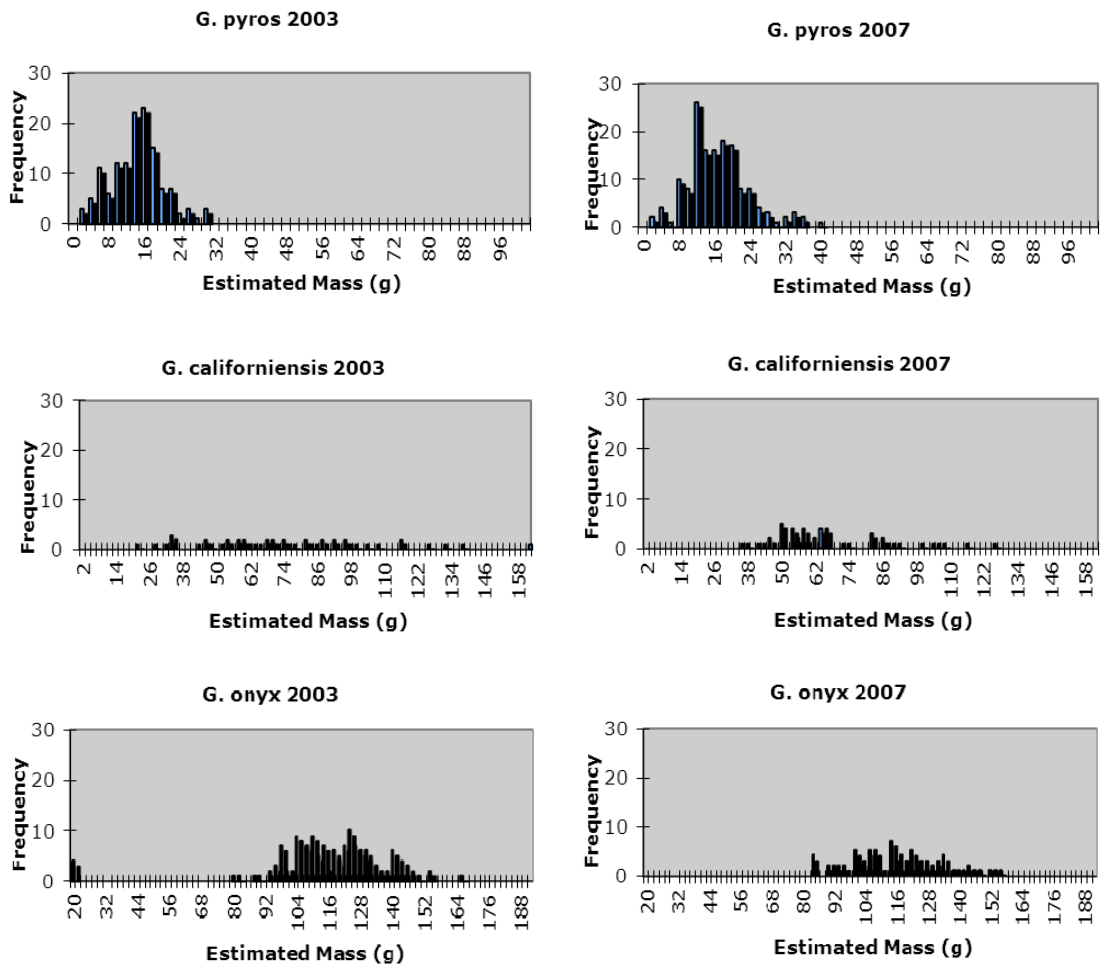


Figure 3. Frequency distribution of estimated masses (g) for *Gonatus pyros*, *G. californiensis*, and *G. onyx* in 2003 and 2007. Regressions were used from Wolff (1984), Clarke et al. (1986), and Walker (in press).

In addition to prey importance, the modified Costello plots represent the feeding strategy of fulmars. Most of the prey items fall in the middle of the plots indicating a generalist foraging strategy and a broad niche width (Fig. 4). Prey items that fall in either “the upper left or lower right corner represent prey types that make the same overall contributions to the population diet, but they are indicative of totally different feeding strategies of individual predators” (Amundsen et al. 1996). In this case, no prey items fall in the upper right hand of the diagrams, indicating no specialization of fulmars (Amundsen et al. 1996). However one prey item, *Doryteuthis opalescens* (commonly called Market Squid), falls in the upper left-hand corner indicating specialization of individual Fulmars when that prey item was available (Fig. 4). Overall, the Fulmars encountered Gonatid squids more than other taxa. Furthermore, the plots indicate a great within-phenotype component with most of the fulmars using many resource types at the same time (Figs.1, 4).

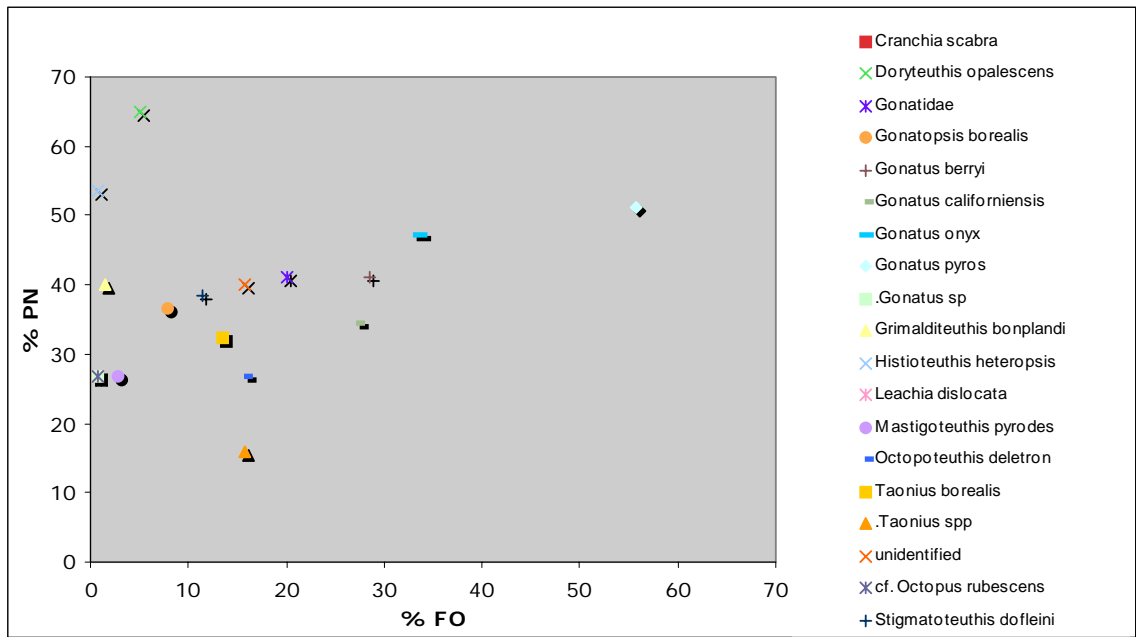
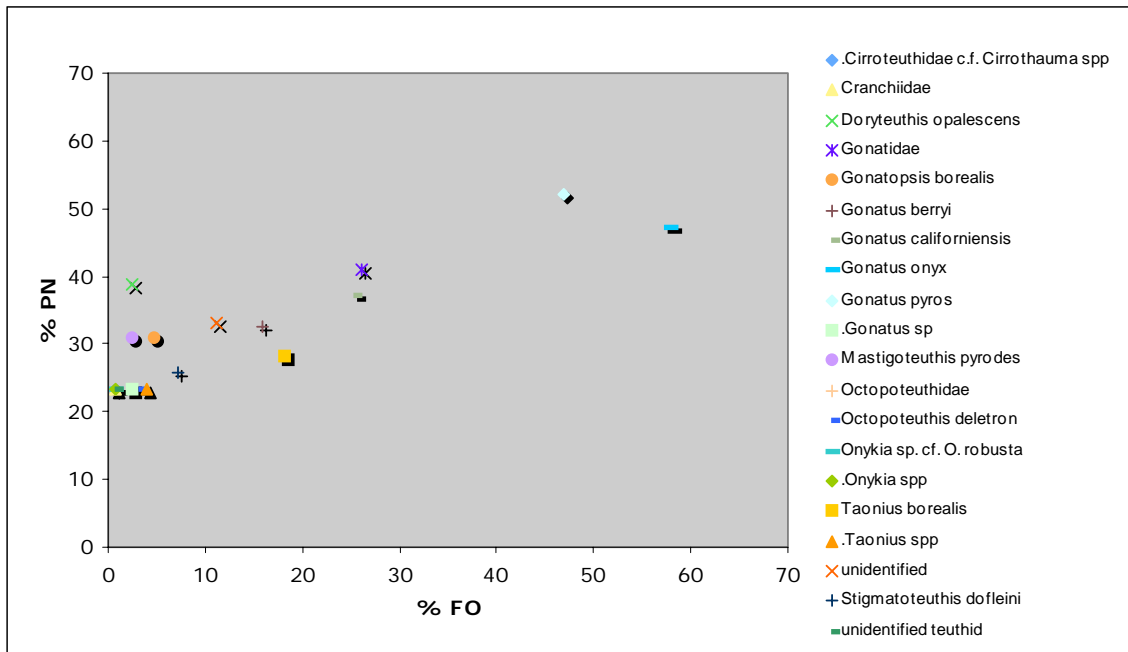


Figure 4. Modified Costello plots (adapted from Amudsen et al. 1996) of identified cephalopods from the Northern Fulmars for 2003 (top) and 2007 (bottom).

In testing for prey differences between years the MANOVA indicated a significant, positive relationship between body condition (pectoral muscle index) and the number (intercept -0.73) and average LRL of cephalopod beaks per stomach (intercept -0.33,  $P = 0.02$ ; Table 3). Where a lesser pectoral muscle index (unhealthy muscle biomass) indicated a lesser number and average LRL of beaks. No significant differences were found in the demographics (sex, age group) or the other body condition variable (subcutaneous fat; Table 3).



Table 3

*MANOVA comparisons of prey variables (number and average lower rostral lengths (mm) of cephalopod beaks per stomach) versus the demographics and body condition indices of Northern Fulmar samples between years and within years (2003 and 2007)*

**Both Years Prey Variables vs. Demographics or Body Condition**

	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.02	1.80	2	215	0.17
AGE_GROUP	1	0.00	0.40	2	215	0.67
PEC_CODE	1	0.03	3.82	2	215	0.02 *
SUBQ_FAT	1	0.01	0.58	2	215	0.56
YEAR	1	0.02	2.25	2	215	0.11

**2007 Prey Variables vs. Demographics or Body Condition**

	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.02	1.37	2	173	0.26
AGE_GROUP	1	0.00	0.23	2	173	0.80
PEC_CODE	4	0.04	0.98	8	348	0.45
SUBQ_FAT	4	0.04	0.88	8	348	0.53

**2003 Prey Variables vs. Demographics or Body Condition**

	DF	Pillai	Approx F	num DF	den DF	Pr(>F)	Pr(>F)
SEX	1	0.07	5.30	2	149	0.01**	0.30***
AGE_GROUP	1	0.03	2.32	2	149	0.10	

\*\* with unknown, female, males

\*\*\* female vs. males

*Note.* The demographics are sex and age group (AGE\_GROUP); the body condition indices pectoral muscle (PEC\_CODE), and subcutaneous fat (SUBQ\_FAT). The Pillai value (Pillai), approximate F value (Approx F), degrees of freedom of the numerator (num DF), degrees of freedom of the denominator (den DF), and the two-tailed significance probability [Pr(>F)]. Comparison with a significant difference marked by an asterisk (\*).

When examining prey difference with-in years, however, the results differed. There were no significant differences in any of the explanatory variables for 2007 (sex, age group, subcutaneous fat, pectoral code) for number and average LRL of cephalopod beaks per stomach (Table 3). There was a significant difference in 2003 between sexes for number and average LRL of cephalopod beaks per stomach when the subcutaneous and pectoral indices were removed. It was deemed appropriate to remove those variables for the 2003 analysis because all fulmars were in 'poor' condition (Table 1; Table 3).

There were differences in some categories of ingested plastics in Fulmars. In 2003, 45 of the 178 samples (25%) did not have any form of plastic, whereas in 2007 only 4 of 185 samples (2%) had no plastic. Incidence of total plastic was 75% in 2003 and 98% in 2007. Overall, the mean number and mass of the plastic categories were greater in 2007 than in 2003 (Table 4). In 2007, there was a significant increase in the ln transformed mass of the user plastic category between Fulmars collected live (SCL;  $\bar{x} = 0.231$ ; SE = 0.03) and dead (SCD;  $\bar{x} = 0.227$ ; SE = 0.06 ) as a result of greater variance in the SCD samples ( $\sigma^2 = 0.43$ ) versus the SCL samples ( $\sigma^2 = 0.07$ ). There were no significant differences in the other plastic categories. Therefore, the rest of the plastic categories for 2007 were pooled for comparisons with 2003 samples, whereas the ln transformed mass of user plastics was analyzed in two steps (SCL vs. 2003 and SCD vs. 2003; Table 5). Because the majority of SCL fulmars died within hours to one week of collection, it was deemed appropriate to compare the SCL and SCD groups. The number

and mass of the four plastic categories were compared between the two years. Significant differences between years were found in the following categories: number and mass of marine debris, number and mass of all plastic, and number of user plastic pieces (Table 6). Significant differences also were found between the SCL vs. 2003 and SCD vs. 2007 masses of user plastics (Table 6).

Table 4

*Mean and Standard Errors (SE) of number and masses (g) of marine debris, all plastic, industrial plastic, and user plastic categories for the 2003 and 2007 samples*

Category	2003		2007	
	Mean	SE	Mean	SE
N_Mar-Debris	9.20	0.68	24.05	1.77
N_Plastic-All	8.98	0.66	22.24	1.63
N_Plastic-Ind	1.37	0.10	1.43	0.11
N_Plastic-User	6.56	0.48	12.44	0.91
G_Mar-Debris	0.15	0.01	0.57	0.04
G_Plastic-All	0.15	0.01	0.47	0.03
G_Plastic-Ind	0.03	0.00	0.03	0.00
G_Plastic-User	0.11	0.01	0.23	0.02

Table 5

*Multivariate Analysis of Variance (MANOVA) comparisons of demographics and body condition indices versus the number and masses (g) of all the plastic categories for the Northern Fulmar samples for 2003 and 2007*

<b>Both Years Demographics or Body Condition vs. Plastic Masses</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.00	0.28	4	297	0.89
AGE_GROUP	1	0.00	0.33	4	297	0.86
PEC_CODE	1	0.01	0.43	4	297	0.79
SUBQ_FAT	1	0.03	2.28	4	297	0.06
<b>Both Years Demographics or Body Condition vs. Plastic Number</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.00	0.27	4	297	0.90
AGE_GROUP	1	0.01	0.74	4	297	0.56
PEC_CODE	1	0.02	1.78	4	297	0.13
SUBQ_FAT	1	0.05	3.52	4	297	0.01 *
<b>2007 Demographics or Body Condition vs. Plastic Masses</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.04	1.79	4	163	0.13
AGE_GROUP	1	0.36	1.54	4	163	0.19
PEC_CODE	4	0.15	1.67	16	664	0.05 *
SUBQ_FAT	3	0.03	0.47	12	495	0.93
<b>2007 Demographics or Body Condition vs. Plastic Number</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.02	0.85	4	163	0.49
AGE_GROUP	1	0.02	0.76	4	163	0.55
PEC_CODE	4	0.10	1.09	16	664	0.36
SUBQ_FAT	3	0.07	0.98	12	495	0.47
<b>2003 Demographics or Body Condition vs. Plastic Masses</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.02	0.86	4	170	0.49
AGE_GROUP	1	0.02	0.74	4	170	0.57
<b>2003 Demographics or Body Condition vs. Plastic Number</b>						
	DF	Pillai	Approx F	num DF	den DF	Pr(>F)
SEX	1	0.02	0.89	4	170	0.47
AGE_GROUP	1	0.01	0.55	4	170	0.70

*Note.* Sex, age group (AGE\_GROUP), pectoral muscle (PEC\_CODE), and subcutaneous fat (SUBQ\_FAT) are shown for both years, 2007, and 2003. The Pillai value (Pillai), approximate F value (Approx F), degrees of freedom of the numerator (num DF), degrees of freedom of the denominator (den DF), and the two-tailed significance probability [Pr (>F)]. Comparisons with significant differences are marked by asterisks (\*).

Table 6

*Analysis of Variance (ANOVA) results of the ln transformed plastic categories where the number and the masses (g) for the 2003 and 2007 fulmars of the following categories were compared: marine debris, all plastic, industrial plastic, and user plastic*

	DF	t	p-value
lnN_Mar-Debris	336	7.98	< 0.001 *
lnN_Pla-All	336	7.50	< 0.001 *
lnN_Pla-Ind	336	0.83	0.407
lnN_Pla-User	336	6.29	< 0.001 *
lnG_Mar-Debris	336	6.41	< 0.001 *
lnG_Pla-All	336	5.66	< 0.001 *
lnG_Pla-Ind	336	1.20	0.231
lnG_PlaUser			
SCL vs. 2003	225	5.09	< 0.001 *
SCD vs. 2003	262	3.02	0.003 *

\* indicates significant value

*Note.* Significant differences between years are asterisked (\*).

The results of the MANOVA indicated number and masses of the plastic categories differed with body condition. There appeared to be a relationship between number of plastics and subcutaneous fat when both years were examined, but this is

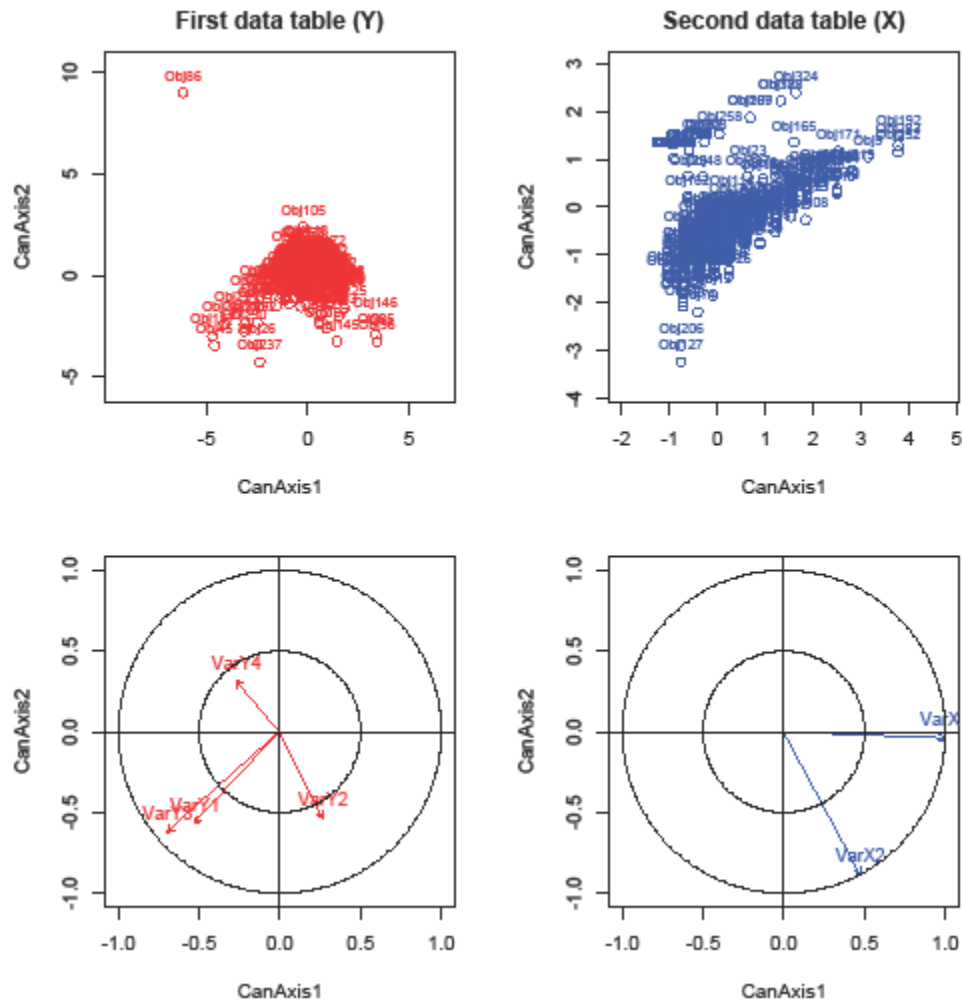
likely due to the overwhelming number of birds of ‘poor’ condition in 2003 (Table 5). When years were examined separately, there was a significant, negative relationship in 2007 between pectoral muscle index and mass of total marine debris, where greater pectoral mass indicated lesser masses of debris (Table 5). There were no differences found for 2003 (with and without the removal of the subcutaneous and pectoral indices; Table 5).

Finally, the Canonical Correlation Analyses indicated there were no significant correlations between the number and mass of plastic compared with the number and size of prey species for each of the two years (Table 7). The graph suggests that, although not significant, there is a negative correlation between the mass of user plastics (Var Y4) and the average LRL per stomach (Var X2) indicated by the vectors pointing in opposite directions (Fig. 5).

Table 7

*Canonical Correlation Analysis correlations between number and mass (g) of the plastic (industrial and user categories) compared with the number and average Lower Rostral Length (mm) of cephalopod beaks per stomach for 2003, 2007, and both years pooled*

Category	P Value	Canonical Correlations	
		CanAxis1	CanAxis2
<b>2003</b>	0.60	0.19	0.08
<b>2007</b>	0.79	0.14	0.08
<b>both years</b>	0.63	0.11	0.08



*Figure 5.* Canonical Correlation Analysis of the plastic variables (red) and cephalopod beak variables (blue). The top left indicates the grouping of all the plastic variables (number and mass) within the samples, whereas the bottom left indicates the vectors of the variables that have been created by the Eigenvalues (Var Y1: number of industrial plastic, Var Y2: number of user plastic, Var Y3: grams of industrial plastic, Var Y4: grams of user plastic; Fig. 6). The top right shows the grouping of the prey variables and

the bottom right indicates the vectors (Var X1: number of beaks, Var X2: average LRL per stomach).

## **Discussion**

The samples from this study represent a subset of the Pacific Northern Fulmar population that migrated to Monterey Bay that was mostly starving, immature, and in poor body condition. The demographics differed slightly, represented by both sexes in 2003, but was predominately male in 2007. Why the fulmars beached is most likely different for each year, as evidenced by difference in body condition and demographics. The fulmars in 2007 were part of the Santa Cruz “Mystery Spill” that initially was considered a clear, petroleum product, but instead was determined to be a non-toxic harmful algal bloom (HAB) of dinoflagellate species (*Akashiwo sanguinea*). This dinoflagellate produced a foam-like substance (Mycosporine-like amino acid) that caused extensive feather fouling and waterproof issues in affected seabirds (Jessup et al. 2009). Both adult and immature birds in poor and healthy condition were observed, but immature fulmars in poor body condition were the majority of the samples. Fulmars in better body condition may have been able to withstand the issues associated with the HAB or were perhaps able to avoid it completely. In the event, it was hypothesized that fulmars in 2003 were birds that originated from colonies in the Gulf of Alaska (Semidi Islands), based on color morph (predominately dark) and satellite telemetry (Hatch 1991; Nevins & Harvey 2005; Hatch et al. 2010). Persistent storms in the winter of 2003 may have reduced their prey availability and prevented foraging (Nevins & Harvey 2005).



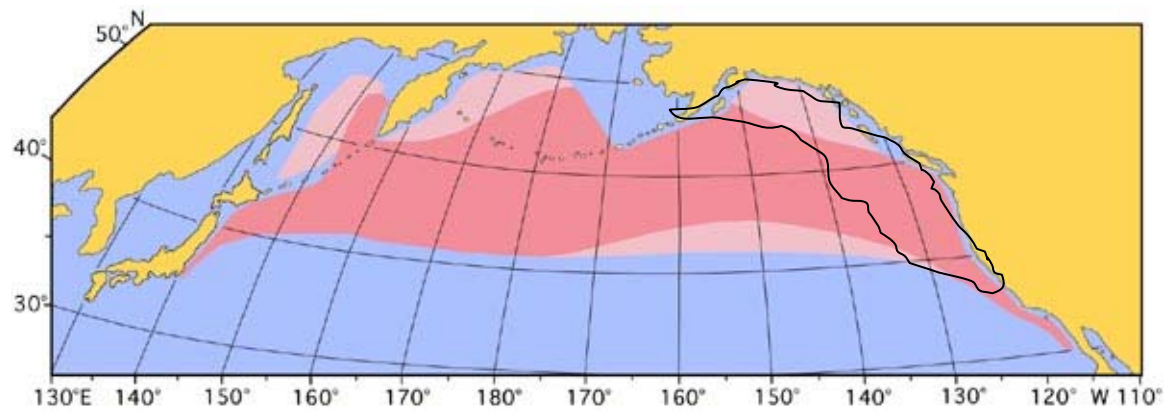
Lethargic, sick, and dead fulmars were observed offshore over the north shelf of Monterey Bay during at-sea surveys, many of these birds likely turned up dead on Monterey beaches (Nevins & Harvey 2005).

During 2002-04, satellite tags were used to track the migration routes of fulmars from the North Pacific breeding sites to the wintering waters (Hatch et al. 2010). Three of the four tagged birds from the Semidi Islands migrated to the California Current System (CCS) off Washington, Oregon, and California and remained over neritic waters of the continental shelf (Hatch et al. 2010; Fig. 6a, b). Based on the tracked fulmars, I assumed that fulmars that were beach-cast in Monterey Bay during 2003 likely came from the Gulf of Alaska and followed similar foraging paths down the coast.

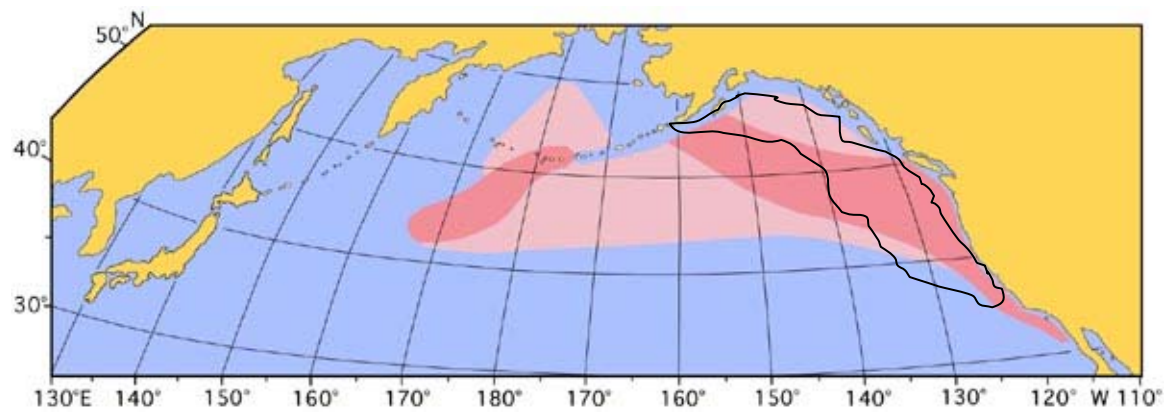
(a) *Gonatus californiensis*



(b) *Gonatus onyx*



(c) *Gonatus pyros*



*Figure 6.* Distributions of the three dominant cephalopod species (a) *Gonatus californiensis*, (b) *G. onyx*, and (c) *G. pyros* in the 2003 and 2007 Northern Fulmar stomach samples. The dark pink regions indicate the known range and the light pink areas indicate the estimated range (Okutani et al. 1988 as cited in Tree of Life Web Project <http://tolweb.org/tree/phylogeny.html>). Black lines represent estimated foraging areas of fulmars (modified from Hatch et al. 2010).

The CalCOFI report for 2003 noted that most of the North Pacific had weakly warm anomalies (from September 03-April 04) indicating a weak to moderate El Niño and positive Pacific Decadal Oscillation (PDO; CalCOFI Rep. Vol. 45). Oceanic trends included unusually strong upwelling throughout the CCS in summer, and strong downwelling in winter off northern California, Oregon, and Washington. Winds over the CCS in summer were persistently to the south (north winds), but strong fluctuations and reversals occurred almost monthly. Other trends were: an increase in southern California sea surface temperatures (SSTs), little or no change in chlorophyll *a* concentrations, no dramatic changes in zooplankton biomass or community structure, and a shift in seabird community structure from temperate cold-species to sub-tropical species. It is likely that these oceanographic features were present when Fulmars were migrating down the coast in 2003.

The CalCOFI report for 2007 noted that a moderate-to-strong La Niña developed by the summer of 2007 (after moderate El Niño conditions in 2006-07) and a negative PDO (CalCOFI Rep. Vol. 49). There were strong north coastal winds with strong upwelling in 2007. The La Niña conditions contributed to average or above-average productivity with the following trends: below normal SSTs in the CCS, above normal chlorophyll *a* concentrations, increased zooplankton biomass off Baja and Oregon (but not off southern California), forage and predatory fish abundance remained low, and low reproductive success of seabirds (monitored at the Farallon Islands). Although the SST

was warmer in 2003 than in 2007, there was no difference in diet of the fulmars in these years leading me to suggest that foraging area of the birds were similar for both years (Fig. 6).

Although oceanographic features differed between the sampled years, the species of cephalopods eaten and the modified Costello plots indicated that the range prey species available to fulmars was similar. Based on these results, I propose that fulmars were foraging opportunistically on the most widely available cephalopods. Fulmars ate mostly on adult, mesopelagic Gonatid cephalopods of varying lengths and masses. Of the three dominant species, *G. californiensis* was the largest, *G. onyx* was somewhat muscular, and *G. pyros* was small and muscular (Nesis 1987). *Gonatus californiensis* is thought to be confined to the CCS region whereas *Gonatus onyx* and *G. pyros* are smaller, more common and broadly distributed species (Fig. 6).

The Fulmar diet described here is similar in species composition as described previously, although in greater detail (Table 8). Previously, researchers were lacking identification to species, distribution information, and sufficient sample sizes when describing Northern Fulmar diet.

Table 8

*Previously identified cephalopod beaks: family, species, number, and location from Northern Fulmar stomachs in earlier decades*

Family	Genus/species	Sanger 1983	Hills & Fiscus 1988	Baltz & Morejohn 1977	Gould et al. 1997
		n = 46	n = 28	n = 3	n = 29
		Gulf of Alaska	Washington Coast	Monterey Bay	West Pacific (near Japan)
<b>Loliginidae</b>	<i>Doryteuthis opalescens</i>	—	—	8	—
<b>Enoploteuthidae</b>	<i>Abrialopsis felis</i>	—	1	—	—
<b>Octopoteuthidae</b>	<i>Octopoteuthis deletron</i>	—	3	5	—
	<i>Octopoteuthis</i> sp.	—	—	—	2
<b>Onychoteuthidae</b>	<i>Onychoteuthis borealijaponicu</i>	—	1	4	—
<b>Gonatidae</b>	<i>Gonatopsis borealis</i>	—	4	—	1
	<i>Gonatus pyros</i>	—	19	—	—
	<i>Gonatus</i> spp.	12	5	—	—
	unid. <i>Gonatidae</i>	—	1	6	—
<b>Histioteuthidae</b>	<i>Histioteuthis heteropsis</i>	—	2	—	—
	<i>Stigmatoteuthis dofleini</i>	—	—	—	#
	unid. <i>Histioteuthidae</i>	—	1	—	—
<b>Ommastrephidae</b>	<i>Ommastrephes bartrami</i>	—	—	—	1
<b>Chroteuthidae</b>	<i>Chroteuthis calyx</i>	—	6	—	—
<b>Mastigoteuthidae</b>	<i>Mastigoteuthis</i> sp.	—	—	—	1
<b>Cranchiidae</b>	<i>Taonius borealis</i>	—	36	—	—
	<i>Galiteuthis phyllura</i>	—	—	—	6
	<i>Leachia dislocata</i>	—	—	—	#
	unid. <i>Cranchiidae</i>	—	1	—	—
<b>Bolitaenidae</b>	<i>Japetella heathi</i>	—	2	—	—
<b>Octopodidae</b>	<i>Octopus</i> sp.	—	1	1	—
<b>Alloposidae</b>	<i>Haliphron atlanticus</i>	—	—	—	#
<b>Unidentified</b>					
	unid. <i>Teuthoidea</i> (juveniles)	—	—	—	1
	unid. cephalopod beaks	—	—	—	5

All three dominant species of cephalopods are primarily mesopelagic, but also found in the bathypelagic zones, which raises the question of how fulmars would have access to deeper water cephalopods. Many cephalopods exhibit vertical diel migrations when in the juvenile stage, which would be one explanation for how Fulmars would have access to deeper water squids especially if they also are nocturnal foragers (Hatch et al. 2010). Another explanation for the abundance of deeper water cephalopods at the surface are die-offs of post-spawning adults. Recently, researchers operating in small vessels used the presence of foraging Procellariiforms to find dead cephalopods floating on the surface. Many of these cephalopods may have floated to the surface after deepwater spawning die-offs. Because most cephalopods eaten by fulmars were mesopelagic species normally found at depth, possibly they were consumed after floating to the surface after deepwater spawning die-offs (personal comm. William Walker 2009).

I found that one body condition index, pectoral muscle, was related to number and average beak size (LRL) per stomach, but the other condition variable, fat score was not. My results and other researchers indicate that assessing muscle complex before sampling will give an estimate of a bird's health (Hobson et al. 1993, van Franeker & Meijboom 2002, Nevins et al. 2005). Furthermore, I found that birds with better pectoral muscle health contained remnants of more prey items suggesting they had been foraging regularly. It is thought that muscle atrophy occurs after fat reserves have been depleted in a fasting or starving bird (van Franeker & Meijboom 2002, Nevins et al. 2005). In this study, the majority of fulmars were in poor health based on the lack of subcutaneous fat

and reduced pectoral muscle mass (driving a significant difference in prey number between years). Ideally, equal representation of healthy vs. poor body conditions would be compared, and is suggested for future studies (Table 1).

Similarly, when examining plastic ingestion and body condition, the pectoral muscle index was an indicator of mass of total marine debris. Birds with greater pectoral muscle indices, the healthy fulmars, contained lesser masses of total debris but not fewer pieces of plastic. These results indicate that healthier fulmars do not ingest less plastic/debris, but plastics/debris that are lesser in mass (Table 5). The total marine debris category includes non-edible items that are not necessarily plastic, but that are not naturally ingested items such as: paper fragments, hardened oil pieces, coal, rubbery pieces, etc. (van Franeker & Meijboom 2002). In Europe, hard plastics are being phased out and lighter, biodegradable items that have a starch component to them are being used (van Franeker personal comm. 2008). If biodegradable plastics break down more readily in fulmar stomachs, they will complicate the quantification of number and incidence of ingested plastics because they are more brittle. This would result in a greater number of plastic pieces, that are lesser in mass. For this reason, it is suggested that mass is a better measure of plastic ingestion in seabirds in the long term and the most representative of ecological impacts on organisms (van Franeker & Meijboom 2002).

This study indicated an overall increase in incidence, number, and mass of plastics between 2003 and 2007. Similar to a study of Fulmars in the North Sea, I found an increase in the plastic categories in all but the industrial plastic category (van Franeker



& Meijboom 2002). Overall, there has been an increase in the amount of user plastic found in seabirds (Vlietstra & Parga 2002, Nevins et al. 2005, van Franeker et al. 2005, Ryan 2008), whereas industrial plastic was more abundant in seabirds sampled in earlier decades (Day et al. 1985, Ryan 1987, Harper & Fowler 1987). Similar plastic loads were found in Short-tailed Shearwaters (*Puffinus tenuirostris*) from the North Pacific sampled between the 1970s and 1990s (Vlietstra & Parga 2002, Ryan 2008). The proportion of industrial pellets, however, had decreased from 55-73% to 33% (Vlietstra & Parga 2002, Ryan 2008). In addition, from 1982 to 2000, fulmars in the North Sea had a significant decrease in ingested industrial plastic, but a significant increase in user plastic (van Franeker et al. 2005). The greater incidences of user plastic in seabirds may reflect an increase in its availability at sea, or conversely, it may reflect a decrease in industrial plastic availability (van Franeker et al. 2005, Ryan 2008). The introduction of programs preventing the loss of industrial pellets in the early 1990s may have reduced the volume of industrial plastic in the ocean (Operation Clean Sweep as cited in Ryan 2008; National Marine Debris Monitoring Program [www.oceanconservancy.org](http://www.oceanconservancy.org)), although more data is needed to test this hypothesis.

I found that the majority of birds were immature fulmars in poor body condition, a factor which could influence plastic ingestion. In addition to variables examined in this study, time, seasonal variation, origin, and cause of death, among other factors could influence the amount and type of plastic ingested (van Franeker & Meijboom. 2002). Often, it is hypothesized that starving birds ingest more plastic. I found that healthy

fulmars in 2007 contained less debris by mass, but not less debris by number. The North Sea fulmar study indicated that plastic loads in stomachs were not related to gradual starving of the bird (van Franeker & Meijboom 2002). Only three birds in the best body condition had lesser plastics (not of statistical significance; van Franeker & Meijboom 2002).

The effect of season on plastic loads in fulmars is less clear. Mallory (2006) found a difference in plastic incidence between breeding and non-breeding fulmars from Canadian colonies. Mallory (2006) did find that there was more plastic in fulmars collected earlier in the breeding season, indicating that the plastic was acquired during winter migration. Similarly, the North Sea breeding and non-breeding adults had greater plastic loads until July, then a decrease in plastic loads occurred, followed by an increase in plastic loads again in the months following (van Franeker personal comm. 2008). This suggests Fulmars are ingesting plastics in wintering areas, breaking it down, and excreting or regurgitating micro plastics to chicks within the breeding season (van Franeker et al. FulmarEcoQO Online Supplement 2011).

A variable that is clearly related to plastic ingestion is age. The North Sea study indicated immatures had greater levels of plastic upon initial inspection (van Franeker & Meijboom 2002), but after additional years in the study (2004-2009), they reported, that the age difference was consistent to a level that all different age groups could be combined in a single monitoring unit (van Franeker et al. 2011). They reported that the geometric mean mass of plastics indicated the same short term annual fluctuations and

long-term patterns for both adults and non-adults, in spite of the substantial difference between these groups (van Franeker & Meijboom 2002, van Franeker et al. 2011). While this indicates that overall patterns in plastic ingestion can be applied to all age groups, this study will reference only immature, wintering Fulmars.

The Canonical correlation results indicated that fulmars carrying heavier loads of user plastic ate smaller cephalopods, but these findings were not statistically significant. These findings may be of biological relevance if trends in plastic ingestion continue. Plastic ingestion is not only increasing in fulmars in the North Sea, it also is increasing in fulmars caught in Alaska's long-line fisheries. Ingested plastic incidence in fulmars was 62% in 2005, but increased to 72% by 2007-08 (Nevins et al. in prep).

As ingested plastic levels increase, one would expect a critical level where dietary changes take place. Although, a critical level would be difficult to identify because it would be species-specific, based on different stomach morphologies, metabolic rates, diets, and retention times. Currently, the retention time of ingested plastics is poorly understood. The interference of ingested plastics on digestion assimilation efficiency was examined in white-chinned petrels (*Procellaria aequinoctialis*) in the 1980s (Ryan 1989). He found no significant difference between petrels fed polyethylene pellets and control birds, but Ryan (1989) suggested testing of other types of plastics should occur. Also, he predicted a half-life of at least one year for pellets in the stomachs of Petrels (Ryan 1989). Similarly, Day et al. (1985) suggested that retention time was approximately 6 months or more for plastic (via wear in the gizzard and passage through the gut).

However, van Franeker et al. (2011) suggested that these papers probably overestimated the residence time of plastics in stomachs. They suggested that disappearance rates of ingested plastics was size dependent, and could be conservatively estimated at greater than 75% per month, (assuming mostly hard plastics) and lesser time for softer plastics (foamed and sheet-like materials; van Franeker et al. 2011). As user plastics increase and pellets decrease (or remain steady) in the marine environment, it becomes imperative to examine the retention times of user plastics. However, experiments that actively feed seabirds plastics are not a widely supported idea for ethical and logistical purposes. Other research that examined retention times focused solely on the time scale or seasons that ingestion was occurring (van Franeker & Bell 1988, Mallory 2008). To understand if there is a critical level and how to define it in seabirds, the first step may be to examine retention times of prey items and hard parts on a species-specific level.

One of the biases with using prey hard parts as a proxy for seabird diet is the difference in passage rates and retention of hard parts, which is often unknown. From marine mammal diet studies, we know that cephalopod beaks are retained in predator stomachs longer than other hard parts, such as fish otoliths (Harvey 1989, Santos et al. 2001). For this reason, the importance of cephalopods in fulmar diet may be overestimated. Although I studied only cephalopod beaks and plastic (the few otoliths recovered were degraded and deteriorating) fulmars forage on a variety of other soft-bodied prey (e.g. amphipods, copepods; Hatch & Nettleship 1998 ). Evidence of fish was found in this study, in addition to small copepods (which may or may not have been

incidental intake). The fulmars sampled in 2003 were spotted by an at-sea survey team eating jellyfish gonads and picking ecto-parasites off of sunfish (*Mola mola*; Nevins & Harvey 2005), although dietary evidence of these prey were not present in my samples due to efficient digestion and less retention of soft-bodied prey. A study on multiple seabird species indicated that species that are generalists and eat a variety of food types (including low quality items) usually had slow and efficient digestion and stomachs with greater mass, whereas seabirds that were specialists ate readily digestible and energy dense food types had faster and less efficient digestion (Hilton et al. 2000). In Cape Petrels (*Daption capense*), squid beaks decreased in number by 90% between December and January. Antarctic Petrels (*Thalassoica antarctica*) and Southern Fulmars (*Fulmarus glacialis*) had the same pattern in cephalopod beak reduction (Van Franeker et al. FulmarEcoQO Online Supplement 2011). Being that beaks are of similar durability as hard plastics, it is assumed that retention times were similar in Northern Fulmars, and that 75% of beaks ingested at the beginning of the month had passed through the digestive system by the end of the month (van Franeker et al. FulmarEcoQO Online Supplement 2011). If this is true and most plastics, cephalopod beaks, and other prey items are retained for about a month, a critical level at which plastics interfere with prey consumption may be of less importance.

How plastic ingestion affects individuals, populations of seabirds, and other marine life is of continued importance as the use of plastics around the world increases. There are other issues with plastic ingestion that are outside the scope of this study that include

contaminants, accumulation, endocrine disrupters, and micro plastics infiltrating prey sources. These issues are key components to understanding how prey and plastic ingestion are correlated, and the overall negative health effects that plastic ingestion have on Northern Fulmars.

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